

Low-Pressure Hydrothermal Processing of Disposable Face Masks into Oils

Cagri Un¹ , Clayton Gentilcore¹ , Kathryn Ault¹ , Hung Gieng² , Petr Vozka² , Nien-Hwa Linda Wang^{1*} 

¹Davidson School of Chemical Engineering, Purdue University, West Lafayette, IN 47907, USA

²College of Natural and Social Sciences, Department of Chemistry and Biochemistry, California State University, Los Angeles, CA 90032, USA

*Correspondence: nwang@purdue.edu (N-H.L.W.)

GC-FID analysis of the oil fractions recovered following batch distillation was conducted using a Shimadzu GC-2010 gas chromatography system paired with an autosampler and flame ionization detector (FID). The detailed method utilized for this analysis is shown in Supplementary-Table S1.

Supplementary Table S1. GC-FID Method for Hydrocarbon Product Analysis

Column	30m×0.32mm×0.25µm HP-5 Column (FID: Front Detector, 20 Hz Data Rate, 0.01 min Minimum Peak Width)
Gases	30 mL/min Make up flow, 40.0 mL/min H ₂ , and 400 mL/min Air Flow
Temperature Program	Chromatogram (Ch1) Interval (msec) 40 Start Time(min) 0.000 End Time(min) 10.250
Equipment Temperatures	Injector: 350°C; Detector: 350°C
Operation Pressures	Injector: Starting at 11.5 psi, Constant Flow
Total Flow and Split Ratio	40 cm/s flow Helium Split Ratio of 120:1
Sample Injections	1 µL of sample injected (every experiment)

The hydrocarbon content was quantified using the data obtained from GC×GC-FID analysis. The detailed contents of these analytical method and results are shown in the Supplementary-Table S2 and S3.

Supplementary-Table S2. GC×GC-FID Method for Hydrocarbon Product Analysis

Instrument	GC×GC-FID
Columns	Rxi-17SilMS (30 m × 0.25mm × 0.25 μm)
	DB-1 HT (1 m × 0.25 mm × 0.10 μm)
	Deactivated (0.38 m × 0.25 mm)
Injection	Split/Splitless, 0.1 μl, 200:1, 285 °C
Carrier gas	UHP He, 1.5 mL/min
Oven program	40 °C (hold 1.5 min)
	40-320 °C, ramp rate 4 °C/min
	320 °C (hold 1 min)
Offsets	Secondary oven: 35 °C
	Modulator: 20 °C
Modulation	1.7 s, hot pulse 0.28 s
FID	300 °C, 200 HZ

The compositions of NW-3, NB-2, FM-2, and FM-1 were analyzed using GCxGC-FID. The results are shown in Supplementary-Table S.3. The compositions of KJ-1 and KJ-2 are referenced in a literature [1].

Supplementary-Table S3. Compositions of Analyzed Oils from GCxGC-FID Analysis.

	NW-3	NB-2	FM-2	FM-1
Non-Hydrocarbon Compounds	0.141	0.191	1.404	2.200
Paraffins				
n-Paraffins	wt. %	wt. %	wt. %	wt. %
n-paraffin C5	0.000	0.000	0.000	0.000
n-paraffin C6	0.000	0.000	0.000	0.000
n-paraffin C7	0.000	0.000	0.000	0.000
n-paraffin C8	0.000	0.000	0.000	0.000
n-paraffin C9	0.000	1.412	0.000	0.000
n-paraffin C10	0.172	1.411	0.000	0.000
n-paraffin C11	0.066	1.447	0.203	0.198
n-paraffin C12	0.021	1.345	0.080	0.165
n-paraffin C13	1.086	1.278	1.387	0.548
n-paraffin C14	0.035	1.158	0.111	0.098
n-paraffin C15	0.000	1.128	0.095	0.077
n-paraffin C16	0.016	1.072	0.098	0.072
n-paraffin C17	0.000	0.984	0.116	0.084
n-paraffin C18	0.000	0.960	0.022	0.020
n-paraffin C19	0.009	0.867	0.094	0.066
n-paraffin C20	0.000	0.873	0.090	0.046
n-paraffin C21	0.000	0.751	0.071	0.044
n-paraffin C22	0.000	0.714	0.101	0.044
n-paraffin C23	0.000	0.652	0.058	0.035
n-paraffin C24	0.000	0.620	0.063	0.035

n-paraffin C25	0.000	0.543	0.061	0.035
n-paraffin C26	0.000	0.512	0.067	0.035
n-paraffin C27	0.000	0.426	0.058	0.006
n-paraffin C28	0.000	0.413	0.066	0.004
n-paraffin C29	0.000	0.359	0.059	0.018
n-paraffin C30	0.000	0.306	0.047	0.022
n-paraffin C31	0.000	0.247	0.056	0.021
n-paraffin C32	0.000	0.207	0.043	0.019
n-paraffin C33	0.000	0.187	0.044	0.017
n-paraffin C34	0.000	0.000	0.062	0.012
n-paraffin C35	0.000	0.000	0.000	0.000
n-paraffin C36	0.000	0.000	0.000	0.000
n-paraffin C37	0.000	0.000	0.000	0.000
total n-paraffins	1.405	19.873	3.153	1.721
Isoparaffins	wt. %	wt. %	wt. %	wt. %
i-paraffin C5	0.000	0.000	0.000	0.000
i-paraffin C6	0.000	0.000	0.000	0.000
i-paraffin C7	0.000	0.000	0.000	0.000
i-paraffin C8	3.289	1.635	0.000	0.000
i-paraffin C9	0.000	0.033	0.000	0.000
i-paraffin C10	0.104	0.129	0.378	0.461
i-paraffin C11	0.537	0.171	1.567	2.803
i-paraffin C12	0.310	0.112	0.156	0.171
i-paraffin C13	0.928	0.161	2.096	1.372
i-paraffin C14	0.496	0.196	0.545	0.564
i-paraffin C15	0.714	0.133	0.702	0.414
i-paraffin C16	1.742	0.172	2.980	1.454
i-paraffin C17	1.265	0.150	1.298	0.870
i-paraffin C18	0.717	0.070	0.812	0.278
i-paraffin C19	2.140	0.099	3.711	1.469
i-paraffin C20	0.959	0.086	1.210	0.578
i-paraffin C21	1.384	0.078	2.526	0.854
i-paraffin C22	0.802	0.062	1.099	0.439
i-paraffin C23	0.507	0.028	0.913	0.395
i-paraffin C24	1.272	0.030	2.337	0.744
i-paraffin C25	0.394	0.011	0.421	0.280
i-paraffin C26	0.793	0.036	1.929	0.589

i-paraffin C27	0.253	0.059	0.300	0.097
i-paraffin C28	0.401	0.000	0.624	0.161
i-paraffin C29	0.549	0.032	1.377	0.411
i-paraffin C30	0.053	0.065	0.013	0.039
i-paraffin C31	0.104	0.001	0.383	0.118
i-paraffin C32	0.585	0.092	1.165	0.371
i-paraffin C33	0.161	0.011	0.291	0.083
i-paraffin C34	0.625	0.221	1.227	0.403
i-paraffin C35	0.126	0.128	0.486	0.126
i-paraffin C36+	0.845	0.219	1.802	0.414
total iso-paraffins	22.054	4.219	32.348	15.959
Cycloparaffins				
Monocycloparaffins	wt. %	wt. %	wt. %	wt. %
monocyclo-paraffin C5	7.997	3.529	6.171	6.821
monocyclo-paraffin C6	6.610	7.147	4.557	7.290
monocyclo-paraffin C7	2.645	3.470	3.576	5.668
monocyclo-paraffin C8	22.494	1.593	19.886	17.861
monocyclo-paraffin C9	3.617	2.873	2.606	3.949
monocyclo-paraffin C10	3.709	2.873	1.042	1.718
monocyclo-paraffin C11	6.047	2.627	5.635	4.147
monocyclo-paraffin C12	2.033	1.030	1.800	1.841
monocyclo-paraffin C13	1.130	0.705	0.854	0.731
monocyclo-paraffin C14	3.871	0.825	4.318	2.483
monocyclo-paraffin C15	0.180	0.409	0.182	0.151
monocyclo-paraffin C16	0.278	0.719	0.286	0.291
monocyclo-paraffin C17	0.839	0.687	0.707	0.246
monocyclo-paraffin C18	0.065	0.694	0.101	0.052
monocyclo-paraffin C19	0.017	0.278	0.085	0.136
monocyclo-paraffin C20	0.012	0.413	0.124	0.095
monocyclo-paraffin C21	0.000	0.794	0.164	0.114
monocyclo-paraffin C22	0.000	0.825	0.198	0.101
monocyclo-paraffin C23	0.000	0.647	0.158	0.071
monocyclo-paraffin C24	0.000	0.563	0.189	0.069
monocyclo-paraffin C25	0.000	1.376	0.408	0.119
monocyclo-paraffin C26	0.000	0.749	0.184	0.009
monocyclo-paraffin C27	0.000	1.274	0.321	0.079
monocyclo-paraffin C28	0.000	1.139	0.396	0.080

monocyclo-paraffin C29+	0.000	0.820	0.420	0.170
monocyclo-paraffin C30+	0.000	0.000	0.000	0.000
total monocyclo-paraffins	61.544	38.058	54.368	54.290
Dicycloparaffins	wt. %	wt. %	wt. %	wt. %
dicyclo-paraffin C8	0.271	1.664	0.272	0.701
dicyclo-paraffin C9	0.303	0.748	0.153	0.532
dicyclo-paraffin C10	1.506	1.774	1.026	2.006
dicyclo-paraffin C11	0.549	1.551	0.130	0.651
dicyclo-paraffin C12	2.486	2.907	1.725	2.938
dicyclo-paraffin C13	0.757	2.854	0.236	0.743
dicyclo-paraffin C14	0.336	2.366	0.189	0.547
dicyclo-paraffin C15	0.687	2.582	0.373	0.700
dicyclo-paraffin C16	0.078	2.213	0.161	0.311
dicyclo-paraffin C17	0.052	1.959	0.140	0.267
dicyclo-paraffin C18	0.029	1.581	0.219	0.166
dicyclo-paraffin C19	0.002	1.706	0.215	0.216
dicyclo-paraffin C20	0.000	1.488	0.211	0.181
dicyclo-paraffin C21	0.000	1.706	0.138	0.155
dicyclo-paraffin C22	0.000	0.704	0.164	0.110
dicyclo-paraffin C23	0.000	0.715	0.147	0.071
dicyclo-paraffin C24	0.000	0.977	0.111	0.081
dicyclo-paraffin C25	0.000	0.962	0.114	0.024
dicyclo-paraffin C26	0.000	0.918	0.170	0.010
dicyclo-paraffin C27+	0.255	0.198	0.046	0.021
total dicyclo-paraffins	7.311	31.575	5.941	10.431
Tricycloparaffins	wt. %	wt. %	wt. %	wt. %
tricyclo-paraffin C10	0.002	0.029	0.001	0.005
tricyclo-paraffin C11	0.001	0.054	0.001	0.014
tricyclo-paraffin C12	0.019	0.059	0.005	0.019
tricyclo-paraffin C13	0.005	0.113	0.004	0.009
tricyclo-paraffin C14	0.031	0.053	0.000	0.026
tricyclo-paraffin C15	0.048	0.027	0.001	0.038
tricyclo-paraffin C16	0.075	0.047	0.001	0.028
tricyclo-paraffin C17	0.045	0.002	0.000	0.001
tricyclo-paraffin C18	0.003	0.027	0.005	0.005
tricyclo-paraffin C19	0.001	0.120	0.004	0.000

tricyclo-paraffin C20	0.000	0.208	0.018	0.009
tricyclo-paraffin C21	0.000	0.197	0.024	0.013
tricyclo-paraffin C22	0.000	0.141	0.014	0.024
tricyclo-paraffin C23	0.000	0.076	0.022	0.013
tricyclo-paraffin C24	0.000	0.056	0.001	0.000
tricyclo-paraffin C25	0.000	0.004	0.000	0.000
tricyclo-paraffin C26	0.000	0.012	0.001	0.000
tricyclo-paraffin C27+	0.000	0.001	0.003	0.026
total tricyclo-paraffins	0.229	1.225	0.103	0.230
total cycloparaffins	69.085	70.858	60.412	64.950
Aromatics				
Alkylbenzenes	wt. %	wt. %	wt. %	wt. %
benzene C6	0.045	0.112	0.249	0.568
toluene C7	0.333	0.402	0.207	0.835
C2-benzene C8	1.048	0.415	0.484	1.932
C3-benzene C9	0.988	0.312	0.392	1.774
C4-benzene C10	0.383	0.223	0.121	0.701
C5-benzene C11	0.218	0.204	0.095	0.385
C6-benzene C12	0.257	0.129	0.081	0.406
C7-benzene C13	0.159	0.102	0.045	0.220
C8-benzene C14	0.071	0.070	0.016	0.093
C9-benzene C15	0.040	0.081	0.016	0.055
C10-benzene C16	0.024	0.062	0.000	0.029
C11-benzene C17	0.042	0.061	0.000	0.003
C12-benzene C18	0.005	0.062	0.000	0.003
C13-benzene C19	0.000	0.030	0.000	0.006
C14-benzene C20	0.000	0.036	0.000	0.010
C15-benzene C21	0.000	0.033	0.000	0.001
C16-benzene C22	0.000	0.028	0.000	0.118
C16-benzene C23	0.000	0.014	0.000	0.007
C16-benzene C24	0.000	0.020	0.000	0.000
C16-benzene C25	0.000	0.009	0.000	0.000
C16-benzene C26+	0.000	0.000	0.000	0.000
total alkylbenzenes	3.613	2.404	1.705	7.145
Cycloaromatics	wt. %	wt. %	wt. %	wt. %
cycloaromatic C9	0.003	0.055	0.004	0.014

cycloaromatic C10	0.073	0.212	0.014	0.159
cycloaromatic C11	0.288	0.218	0.094	0.575
cycloaromatic C12	0.465	0.286	0.122	0.854
cycloaromatic C13	0.514	0.229	0.072	0.894
cycloaromatic C14	0.342	0.145	0.024	0.528
cycloaromatic C15	0.255	0.061	0.003	0.221
cycloaromatic C16	0.053	0.008	0.000	0.023
cycloaromatic C17	0.016	0.022	0.000	0.010
cycloaromatic C18	0.000	0.033	0.000	0.003
cycloaromatic C19	0.001	0.016	0.000	0.003
cycloaromatic C20	0.000	0.021	0.000	0.040
cycloaromatic C21	0.000	0.011	0.000	0.069
cycloaromatic C22	0.000	0.014	0.000	0.005
cycloaromatic C23	0.000	0.014	0.000	0.000
cycloaromatic C24	0.000	0.008	0.000	0.000
cycloaromatic C25	0.000	0.004	0.000	0.001
cycloaromatic C26+	0.000	0.000	0.000	0.000
total cycloaromatics	2.011	1.357	0.332	3.397
Alkyl naphthalenes	wt. %	wt. %	wt. %	wt. %
naphthalene C10	0.006	0.028	0.012	0.027
alkyl naphthalenes C11	0.030	0.075	0.045	0.113
alkyl naphthalenes C12	0.083	0.075	0.011	0.181
alkyl naphthalenes C13	0.088	0.095	0.020	0.163
alkyl naphthalenes C14	0.101	0.093	0.000	0.149
alkyl naphthalenes C15	0.217	0.106	0.000	0.374
alkyl naphthalenes C16	0.250	0.045	0.000	0.232
alkyl naphthalenes C17	0.220	0.011	0.000	0.052
alkyl naphthalenes C18	0.041	0.022	0.000	0.061
alkyl naphthalenes C19	0.008	0.010	0.000	0.000
alkyl naphthalenes C20	0.005	0.003	0.000	0.008
alkyl naphthalenes C21	0.000	0.000	0.000	0.001
alkyl naphthalenes C22	0.000	0.000	0.000	0.000
alkyl naphthalenes C23	0.000	0.014	0.000	0.000
alkyl naphthalenes C24	0.000	0.000	0.000	0.000
alkyl naphthalenes C25+	0.000	0.000	0.000	0.001
total naphthalenes	1.048	0.578	0.088	1.361

Biphenyls	wt. %	wt. %	wt. %	wt. %
triaromatics C12	0.002	0.000	0.082	0.168
triaromatics C13	0.006	0.013	0.034	0.113
triaromatics C14	0.013	0.057	0.031	0.168
triaromatics C15	0.051	0.072	0.024	0.185
triaromatics C16	0.059	0.091	0.000	0.321
triaromatics C17	0.082	0.068	0.000	0.324
triaromatics C18	0.124	0.033	0.000	0.380
triaromatics C19	0.083	0.029	0.000	0.100
triaromatics C20	0.045	0.003	0.000	0.302
triaromatics C21	0.000	0.003	0.000	0.164
triaromatics C22	0.000	0.000	0.000	0.113
triaromatics C23	0.058	0.008	0.000	0.099
triaromatics C24	0.016	0.000	0.000	0.012
triaromatics C25	0.000	0.000	0.000	0.002
triaromatics C26+	0.000	0.000	0.000	0.000
total biphenyls	0.539	0.376	0.171	2.452
Phenanthrenes + Anthracenes	wt. %	wt. %	wt. %	wt. %
Ph C14	0.000	0.000	0.015	0.035
Ph C15	0.000	0.000	0.015	0.012
Ph C16	0.000	0.011	0.000	0.001
Ph C17	0.000	0.019	0.000	0.049
Ph C18	0.000	0.000	0.000	0.088
Ph C19	0.013	0.009	0.000	0.042
Ph C20	0.027	0.029	0.003	0.138
Ph C21	0.034	0.000	0.000	0.060
Ph C22	0.000	0.000	0.000	0.000
Ph C23+	0.000	0.000	0.000	0.046
total phenanthrenes + anthracenes	0.075	0.068	0.033	0.470
Pyrenes	wt. %	wt. %	wt. %	wt. %
Py C16	0.006	0.000	0.059	0.071
Py C17	0.005	0.012	0.103	0.208
Py C18	0.000	0.012	0.000	0.009
Py C19	0.000	0.000	0.030	0.031
Py C20	0.000	0.044	0.027	0.020
Py C21	0.005	0.008	0.001	0.001

Py C22	0.014	0.000	0.034	0.003
Py C23	0.000	0.000	0.100	0.000
Py C24+	0.000	0.000	0.000	0.000
total pyrenes	0.030	0.075	0.354	0.345
total aromatics	7.315	4.859	2.683	15.169
TOTAL	100.000	100.000	100.000	100.000

Supplementary-Table S4. Experimental Conditions and Product Yields from Individual FM-1 Runs

Exp. No.	Set Temp., T_s (°C) and Set Time, t_s (min.)	Effective Average Temp., T_{EAV} (°C)	Effective Reaction Time, t_{ER} (min.)	Oil Yield %	Gas Yield %	Wax Yield %	Char Yield %
FM-1a	450-10	396	32	81.5	17.6	0	0.8
FM-1b	450-10	403	30	81.9	17.4	0	0.7
FM-1c	450-10	405	28	81.7	17.2	0	1.1

Supplementary-Table S5 shows a comprehensive overview of the compositions of various distilled oils with different fractions. These fractions include Naphtha, Middle Distillate, and Heavy Oil. The data in this table pertains to a range of oil samples, including NW-1, NW-2, NW-3, NW-4, NB-1, NB-2, EL-1, FM-1, and FM-2.

Supplementary-Table S5. Weight Fractions of Distilled Oils

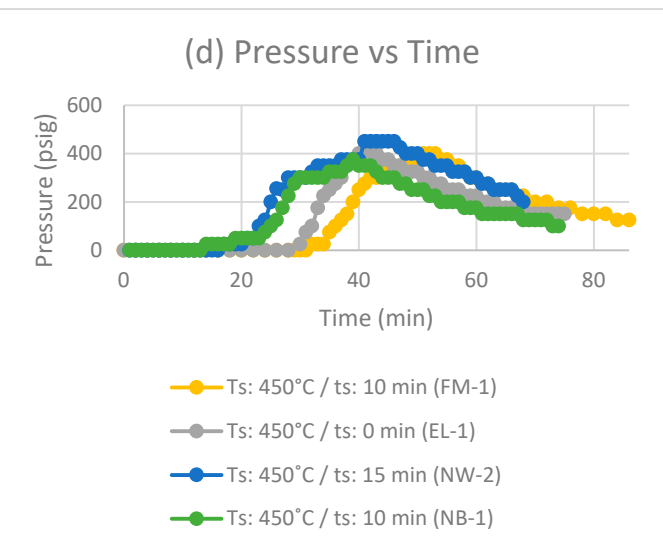
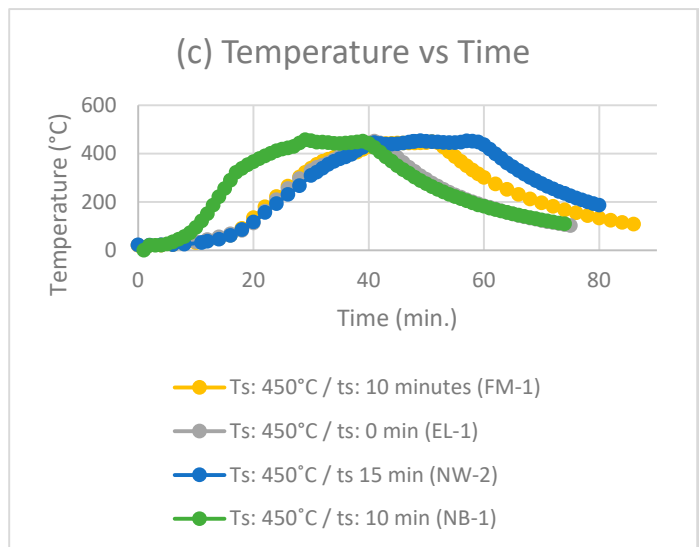
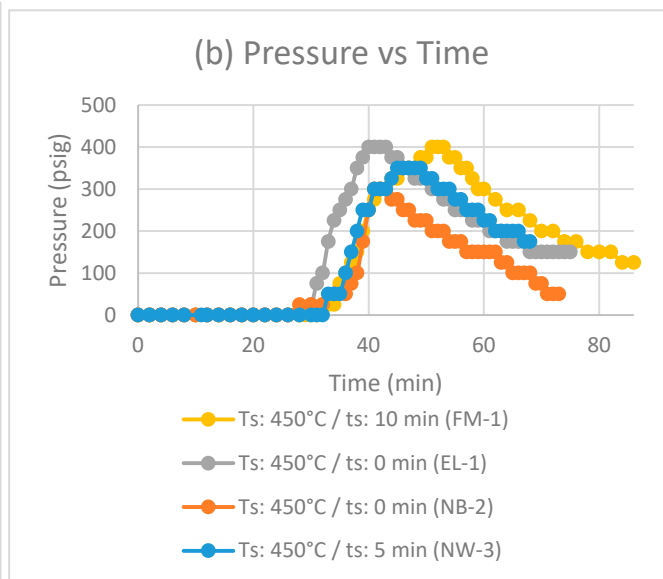
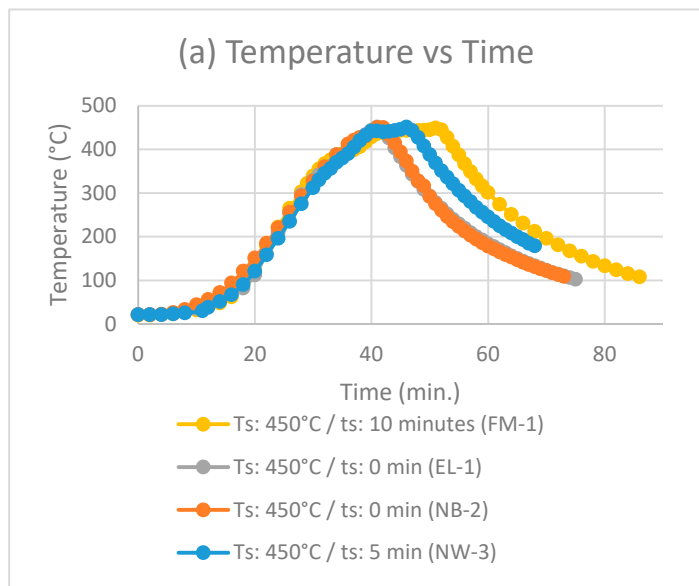
Fraction	NW-1	NW-2	NW-3	NW-4	NB-1	NB-2	EL-1	FM-1 (3 trials)	FM-1a	FM-1b	FM-1c	FM-2
Naphtha %	70.5	69.4	61.8	63.0	50.7	45.6	-	50.9±0.8	50.4	52.0	50.2	27
Middle Distillate %	12.3	12.5	22.1	20.0	23.0	20.7	-	20.3±0.4	20.2	21.0	19.7	33
Heavy Oil %	17.2	18.1	16.1	17.0	26.3	33.7	-	28.8±1.2	29.2	27.0	30.1	40

Net energy and GHG emission calculations can be found in the Supplementary-Table S6.

Supplementary Table S6. Estimated energy inputs, outputs and GHG emissions for LP-HTP, incineration, and landfill

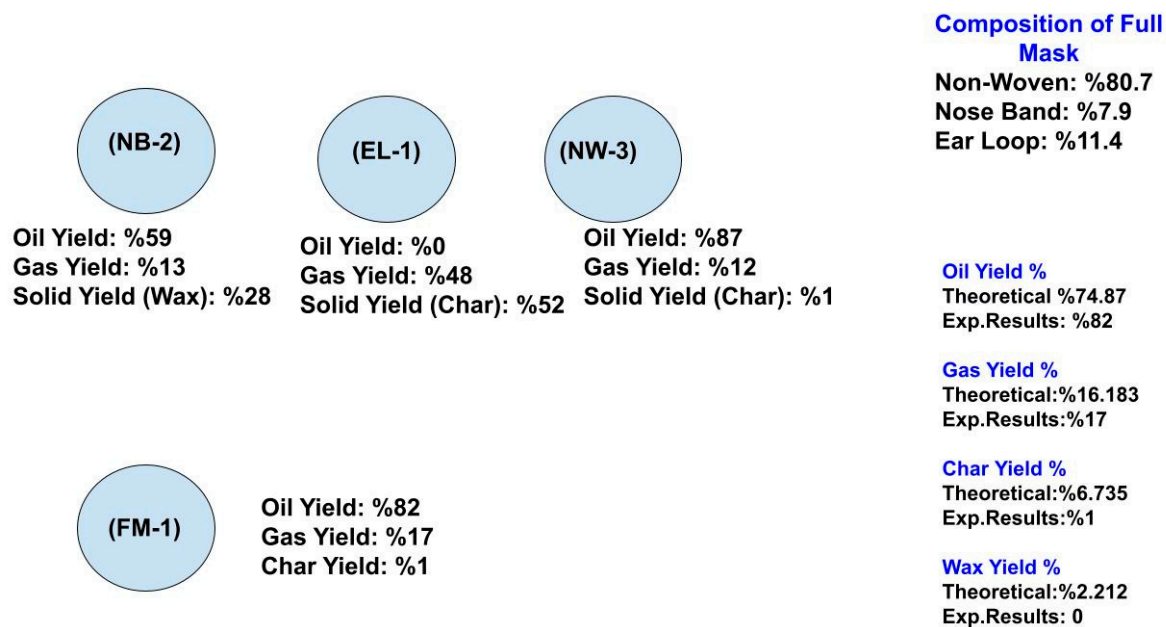
Methods of Face Mask Disposal	Energy Inputs (MJ / kg face masks)	Energy Outputs (MJ / kg face masks)	Difference of Energy Outputs and Inputs (MJ / kg face masks)	GHG Emissions (kg CO ₂ / kg face masks)
LP-HTP	1.46 ^a	43.19 ^b	41.73	0.10 ^c
SWL	7.04 ^a	34.41 ^b	27.37	0.47 ^c
Pyrolysis	1.33 ^a	39.51 ^b	38.18	0.09 ^c
Incineration	1.79 ^d	14.06 ^e	12.27	1.83 ^f
Landfilling	0.38 ^g	~0	-0.38	0.15 ^h

- a. For LP-HTP, SWL, and pyrolysis, 1.3 MJ/kg required for polyolefin conversion. 0.16 MJ/kg required for water heating in LP-HTP, and 5.74 MJ/kg required for water heating in SWL. Pyrolysis upgrading processes require 0.03 MJ/kg. [1]
- b. Based on yields of 82 wt.% oil and 17 wt.% gas (FM-1) from LP-HTP, assuming the oil has the energy content of crude oil (43.05 MJ/kg, <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4687841/>) and the gas has the energy content of propane (46.4 MJ/kg, https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html). This gas composition is assumed based on gases produced from PP and HDPE pellets in previous LP-HTP studies [1] and the composition of gas from ear-loops (EL) is not considered. Furthermore, energy outputs from pyrolysis and SWL are based on their respective oil and gas yields shown in previous literature, with 81 wt.% oil and 10 wt.% gas from pyrolysis [2], and 67 wt.% oil and 12 wt.% gas from SWL [3].
- c. Based on propane combustion for required energy input, with assumed 90% efficiency [1]
- d. Based on reported energy inputs from polyolefin waste incineration [4].
- e. Based on reported energy recovery from polyolefin waste incineration (Vlasopoulos 2023). Values from Vlasopoulos are based on case studies using “default” polyolefin waste streams [4].
- f. Based on reported greenhouse gas emissions from polyolefin waste waste incineration (Vlasopoulos 2023). Values from Vlasopoulos are based on case studies using “default” polyolefin waste streams and based on the global warming potentials (GWP) [4].
- g. Based on reported energy inputs for polyolefin waste landfilling (Vlasopoulos 2023). Values from Vlasopoulos are based on case studies using “default” polyolefin waste streams [4].
- h. Based on reported greenhouse gas emissions for polyolefin waste landfilling (Vlasopoulos 2023). Values from Vlasopoulos are based on case studies using “default” polyolefin waste streams and based on the global warming potentials (GWP) [4].



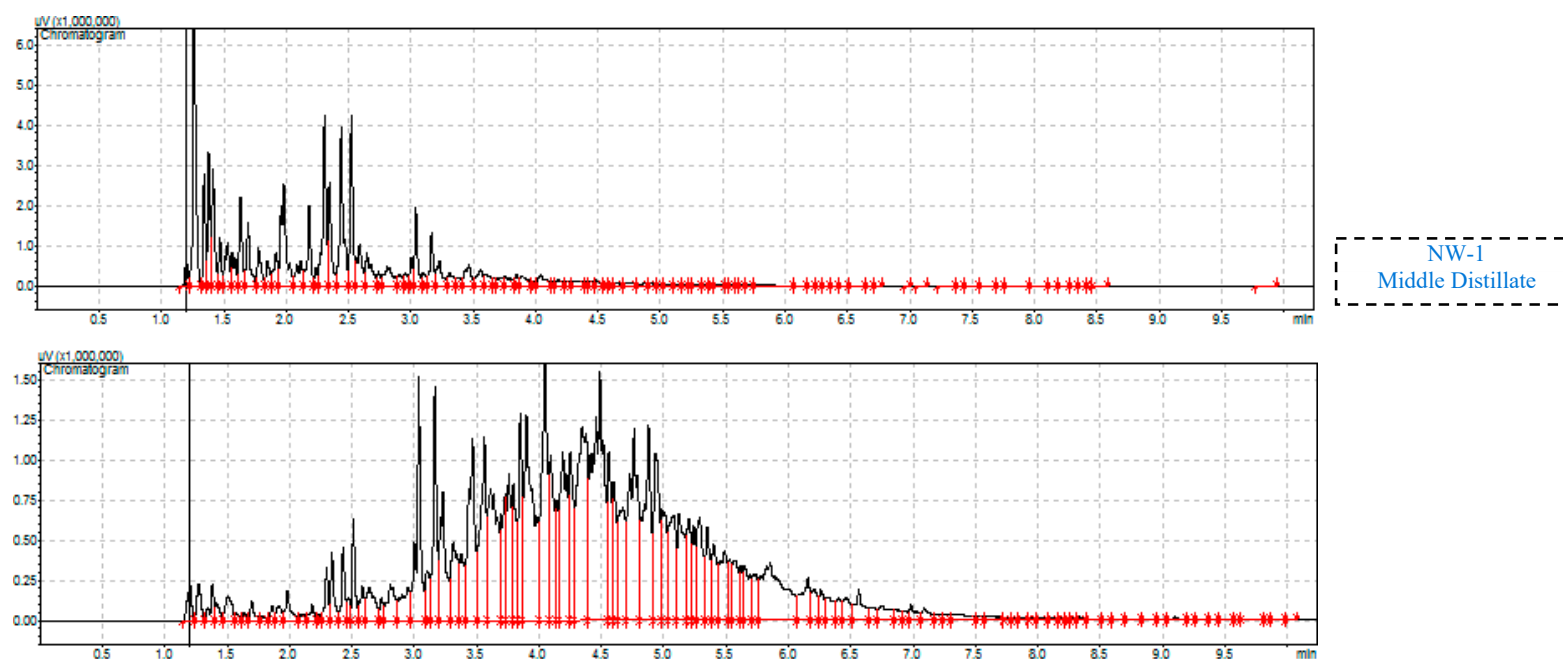
Supplementary- Figure S1. (a) Temperature vs time and (b) Pressure vs time profiles for FM-1, EL-1, NB-2, NW-3 experiments. (c) Temperature vs time and (d) Pressure vs time profiles for FM-1, EL-1, NW-2, NB-1 experiments.

When assuming independent conversion reactions for HDPE, PP, and Polyester+Spandex within the FM process, as calculated in Supplementary-Figure S2, the FM-Theoretical model had initially predicted a 7% char yield. However, the actual char yield obtained in FM-1 production was significantly lower, at only 1%."

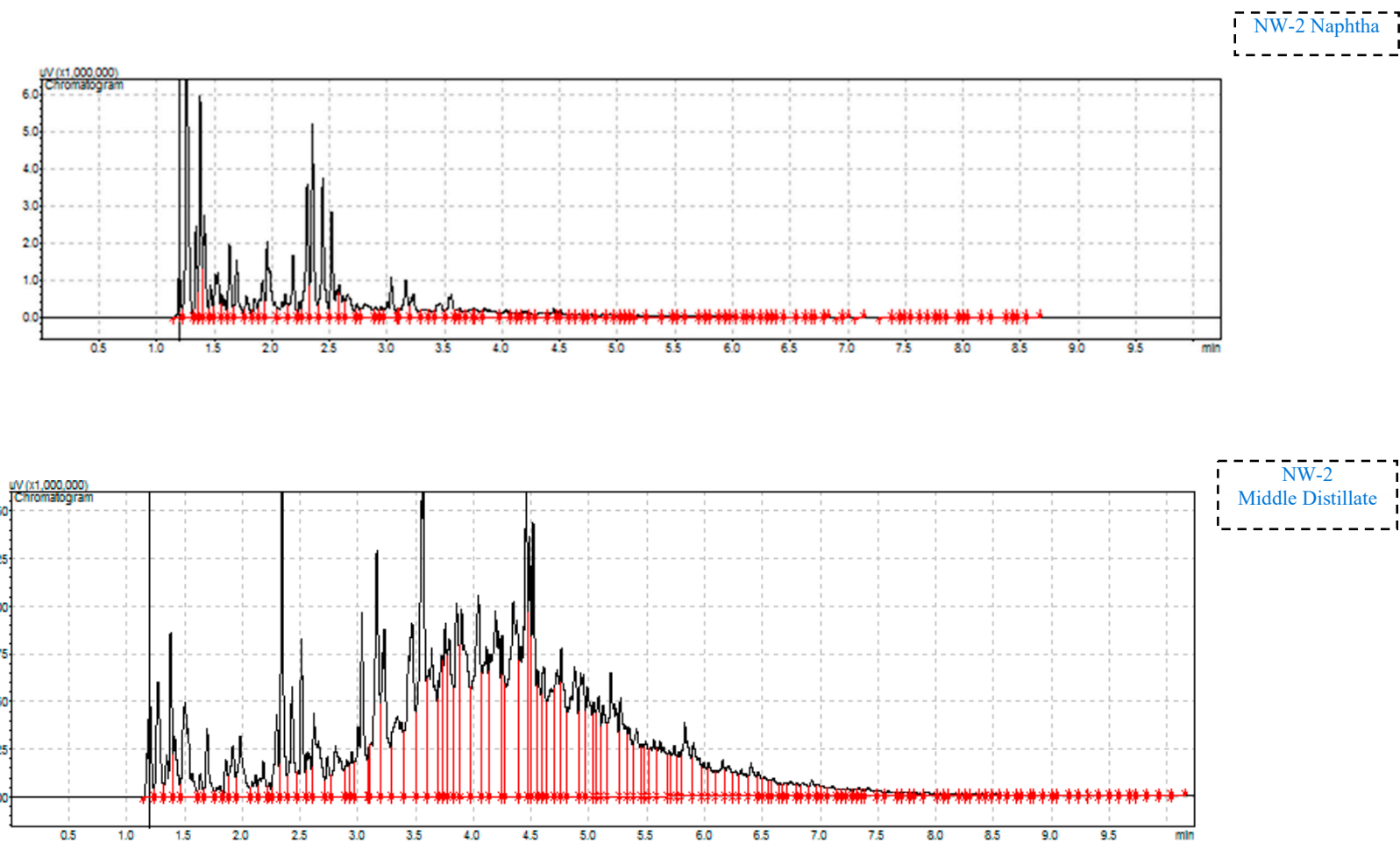


Supplementary-Figure S2. The theoretical calculations of NB-2, EL-1, NW-3 and FM-1

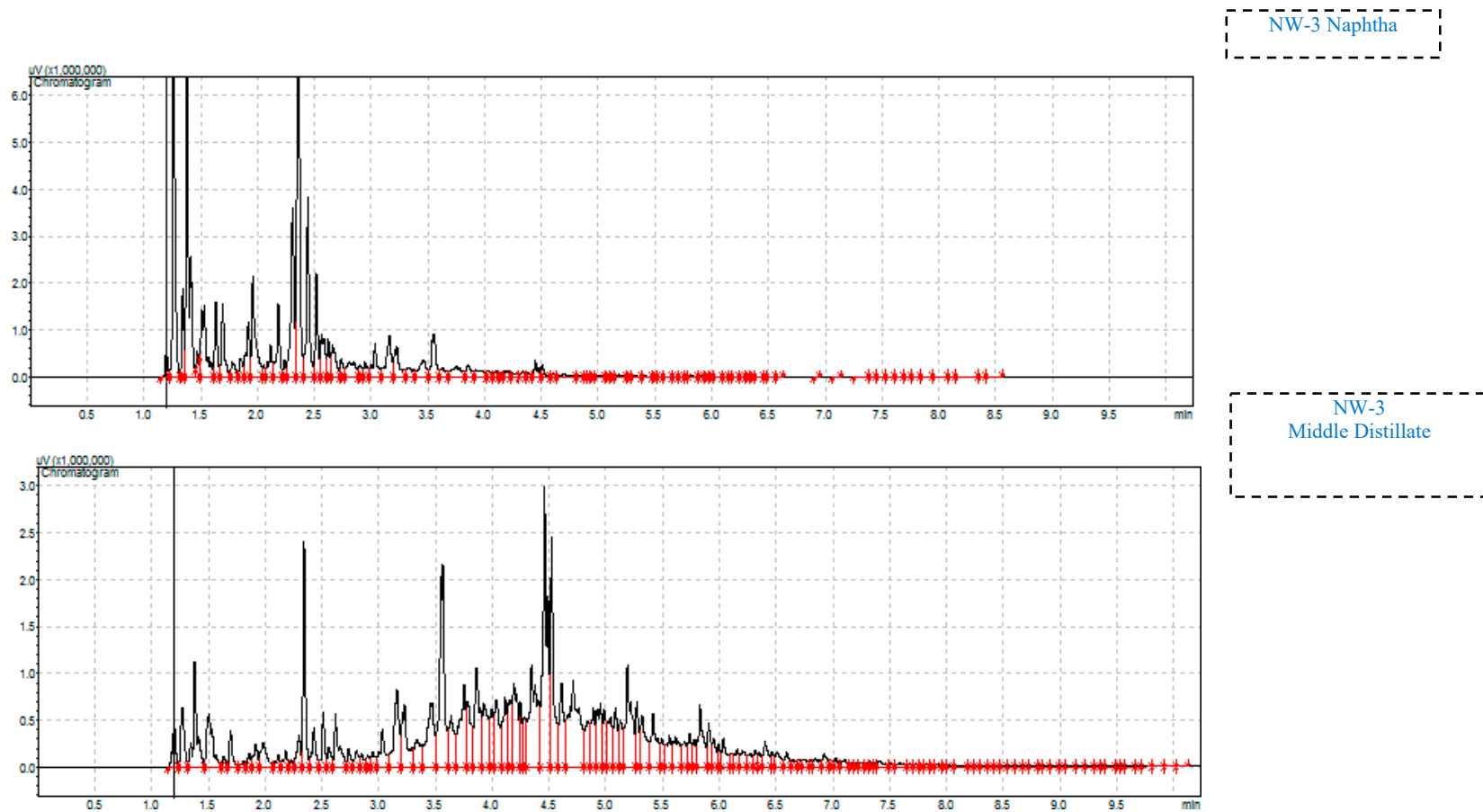
The GC-FID results of naphtha and middle distillate, obtained from the distillation of NW experiments, were shown in Supplementary-Figures S3–S7. Comparative analysis was conducted using commercially available gasoline, diesel and oil mix (C8-9=10=12-14-16).



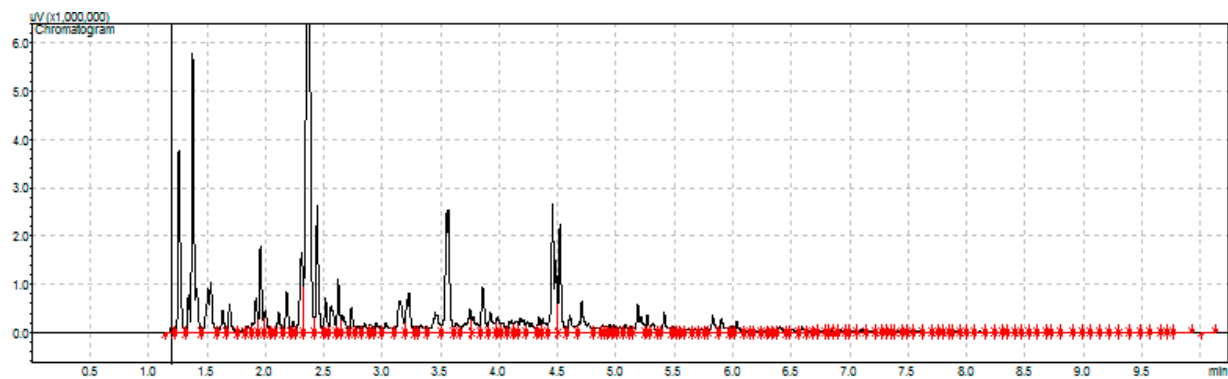
Supplementary-Figure S3. GC-FID results of NW-1 naphtha and NW-1 middle distillate



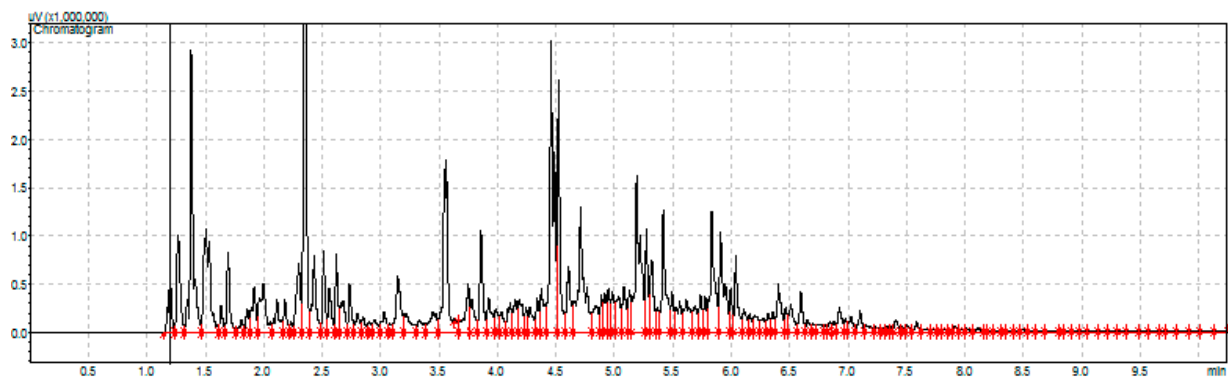
Supplementary-Figure S4. GC-FID results of NW-2 naphtha and NW-2 middle distillate



Supplementary-Figure S5. GC-FID results of NW-3 naphtha and NW-3 middle distillate

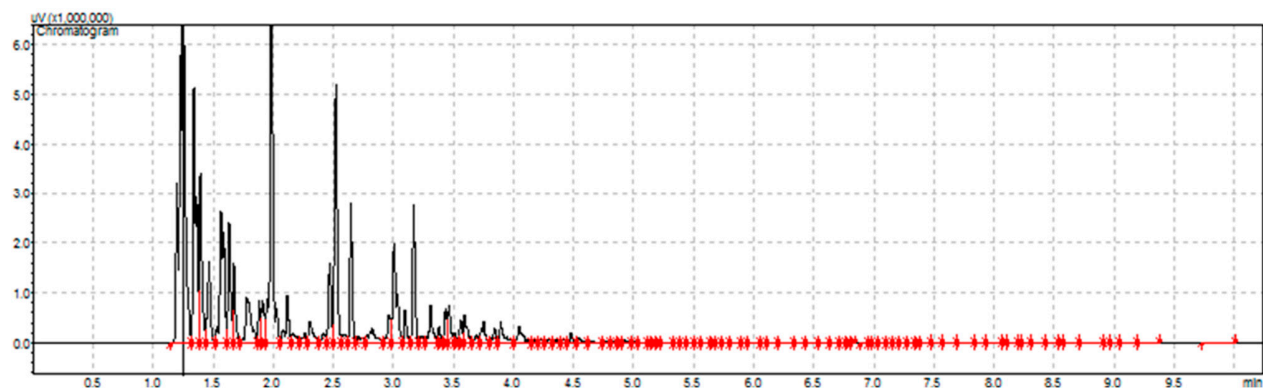


NW-4 Naphtha

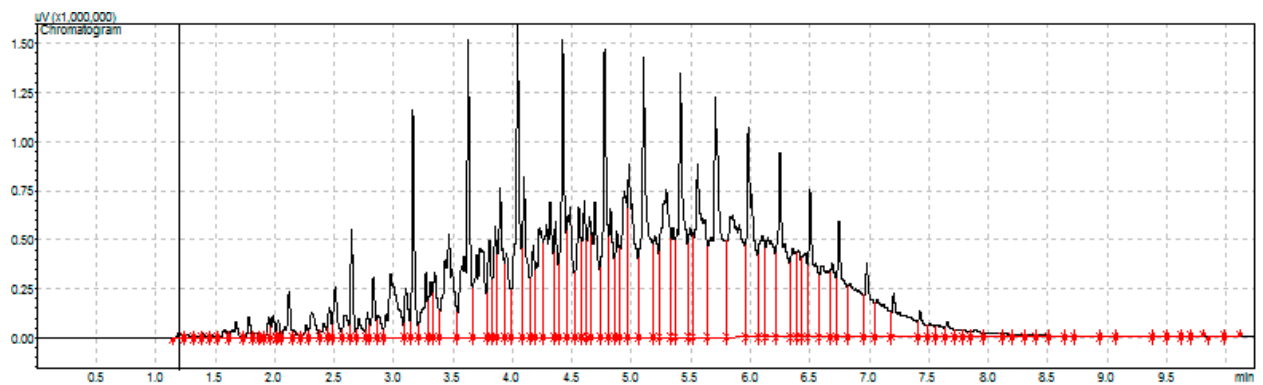


NW-4
Middle Distillate

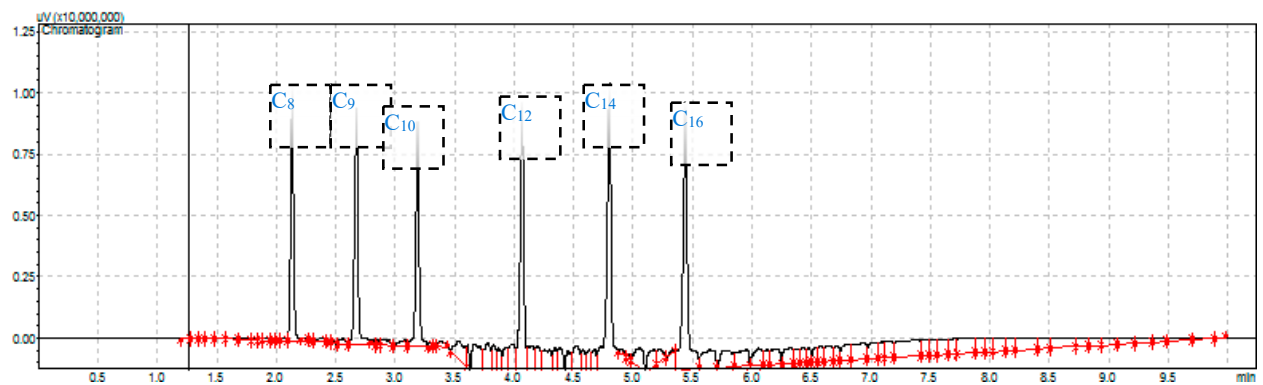
Supplementary-Figure S6. GC-FID results of NW-4 naphtha and NW-4 middle distillate



Commercial
Gasoline Sample



Commercial
Diesel Sample



Oil Mix Sample
For
Reference
Points

Supplementary-Figure S7. GC-FID results of Commercial Gasoline Sample, Commercial Diesel Sample, and Oil Mix Sample for Reference Points

References for Supplementary Materials

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